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Root storage of nitrogen applied in autumn and its remobilization to new growth in spring of persimmon trees (*Diospyros kaki* cv. Fuyu)

Young Kee Kim [a,*], Chae Shin Lim [a], Seong Mo Kang [a,b], Jeong Lai Cho [a,b]

[a] Department of Horticulture, Division of Applied Life Science, Gyeongsang National University, Jinju 660-701, Republic of Korea
[b] Institute of Agriculture & Life Sciences, Gyeongsang National University, Jinju 660-701, Republic of Korea

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ABSTRACT

This study was conducted to understand the effect of N supply in autumn on its uptake and distribution in tree parts and the utilization of reserve N the following year in persimmon trees (*Diospyros kaki* cv. Fuyu). The treated trees received 22.5-g N each for two successive years as a 3.5% urea solution from September 18 at 5-day intervals. Trees absorbed about 30% on average of the N applied in autumn. Sixty four to 83% of the N absorbed in autumn was in perennial parts, and 65–72% of that was in roots. Total N in perennial parts of the tree fertilized with N increased by over 4.28 g while leaf N changed little during senescence, indicating that the reserve N was constituted mostly by the N absorbed in autumn. Total N in the new growth was about the same as the amount of N declined in spring from perennial parts, indicating that there was little contribution by soil N to sustain new growth. Total dry weights of new growth the following year in a with-N tree were greater by over 34 g than those in a without-N tree.

1. Introduction

Several studies have been conducted to understand the nitrogen (N) absorption, accumulation and its internal cycling in deciduous fruit trees (Taylor et al., 1975; Titus and Kang, 1982; Acuña-Maldonado et al., 2003; Cheng et al., 2004). However, since tree responses to the N applied in autumn vary with tree species (Niederholzer et al., 2001; Acuña-Maldonado et al., 2003), our understanding for its efficiency is far from complete.

Deciduous trees accumulate N in perennial parts by resorption from senescing leaves (Titus and Kang, 1982; Blasing et al., 1990). During senescence, more than 50% of leaf N is remobilized into perennial parts of apple (Oland, 1963), pear (Sanchez and Righetti, 1990), and peach trees (Niederholzer et al., 2001). Approximately 50% of leaf proteins decline during senescence of apple trees (Spencer and Titus, 1972; Shim et al., 1972). Niederholzer et al. (2001) observed that the N remobilized from the leaves accounted for more than 80% of the N stored in perennial parts. However, little leaf N was remobilized into perennial parts of pecan trees during leaf senescence (Acuña-Maldonado et al., 2003). On the other hand, the N accumulated in perennial parts of deciduous trees is also constituted by the N absorbed in autumn (Taylor and van den Ende, 1969, 1970; Weinbaum et al., 1978; Titus and Kang, 1982; Tagliavini et al., 1999). Tagliavini et al. (1999) reported that the N absorbed in autumn was mostly accumulated in perennial parts, and 73–80% of total N in dormant trees was in the roots.

Unlike apple (Neilsen et al., 1997) and pear trees (Tagliavini et al., 1997), flowering occurs after the termination of shoot growth in persimmon, so that it is likely that reserve N is preferentially utilized to support shoot growth in early spring. Fukui et al. (1999) reported the fate of N in each part of a persimmon tree after applying it from June to September, but N distribution among tree parts remains unclear when it is supplied in late autumn. The objectives of this experiment were to understand the effect of N supply in autumn on its uptake and distribution among tree parts and the utilization of reserve N for new growth the following year of persimmon trees.

2. Materials and methods

2.1. Plant materials

Three-year-old trees of persimmon (*Diospyros kaki* cv. Fuyu), grafted on 'Fuyu' seedlings, were used in both experiments described below. The trees were grown in 30-L pots containing a 3:1 (v/v) mixture of sandy loam and compost manures. The pots were completely randomized with three single-tree replications. These trees were grown to two scaffolds in a rain shelter in Jinju, Korea. Each tree pot was supplied five equal proportions (12-day intervals) with a total of 22 g of urea, 56 g of $CaH_4(PO_4)_2$ and 32 g of

* Corresponding author. Tel.: +82 55 758 7438; fax: +82 55 758 7438.
E-mail address: kim071@hanmail.net (Y.K. Kim).

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KCl through a solution in April and May every year before the experiment. During the experimental period, the same amount of $CaH_4(PO_4)_2$ and KCl was applied only for 2 months. After adjusting the leaf–fruit ratio (20:1) in early July, number of fruits in a 3- and 4-year-old tree at harvest ranged from 6 to 9 and 12 to 16, respectively. In a 5-year-old tree, the experiments were terminated when the primary shoot growth ceased by May 24; the number of flower buds per tree at that time ranged from 15 to 204 depending on the treatment.

2.2. Treatments and repetition of the experiment

Nitrogen was soil-applied seven times as 200 mL of 3.5% (w/v) urea from September 18 at 5-day intervals. The treated trees received a total of 22.5-g N (+N trees), and those trees receiving 200 mL of tap water served as the controls (−N trees). The whole experiments were repeated twice in an identical manner. The first set of experiment (Expt. I) was conducted from the autumn (September 18 of 2002) to the spring (May 24 of 2004), and the second set (Expt. II) from the autumn (September 18 of 2003) to the spring (May 24 of 2005). For Expt. I, the first year treatment was initiated on September 18 of 2002 (Expt. I-FY), and the second year treatment on the same date of 2003 (Expt. I-SY). The first and second year treatments for Expt. II were the same as for Expt. I, but conducted in 2003 and 2004, and they are referred to as Expt. II-FY and Expt. II-SY, respectively.

2.3. Tree harvest and sample preparations

Excluding the three trees harvested on September 18 (initiation of the third stage of fruit growth) for N analysis of the first and second year treatments, three replicate trees were destructively harvested on January 20 (dormant), April 1 (bud germination), and May 24 (termination of shoot growth). Therefore, when N was applied in the second year for Expt. I-SY and Expt. II-SY, nine trees were left to receive N and another nine to receive no N. On November 10 each year, the leaves and the matured fruits were harvested from individual trees to assess the amount of N being removed from that tree. About half of leaves had been abscised by November 10 in our study and were collected with nylon nets. The leaves still attached to the trees were severely withered when harvested. Harvested trees were separated into leaves, fruits, shoots, old woods, and the roots that included the aboveground part of the rootstock. New growth of the shoots was measured on 24 May the following year. All samples were dried at 80 °C for 48 h before measuring dry weight (DW). Samples were ground to pass through a 20-mesh screen.

2.4. Nitrogen analysis

To determine total N, 0.2 g of sub-samples were analyzed with the Kjeltec 2300 Analyzer Unit (Foss Co., Höganäs, Sweden) by using the micro-Kjeldahl method (Pieterzyk and Frank, 1979). The changes of N that occurred from September 18 to January 20 in different parts of a tree were calculated by subtracting the average N content of September from that of January. To estimate the amount of N absorbed during this period, the changed N content of the −N trees were subtracted from that of the +N trees to eliminate the effect of the N present in the medium and/or released from organic forms. The percentage of total N distributed in tree parts was then calculated.

2.5. Statistical analysis

To test for the effects of nitrogen treatment and harvest dates, results were analyzed by ANOVA using SAS General Linear Model (SAS Institute, Cary, N. C.).

3. Results and discussion

The trees fertilized with N in September and October contained more N in January of the following year than the trees that were not fertilized (Table 1). Perennial parts of the tree contained 57–70% of total tree N. In the +N trees, the amount of N in tree parts, especially in the root, increased after the first and second year of treatments. The root proportion of total tree N in the −N trees was similar to that in the +N trees in the first year of treatments ($P > 0.05$), but it was not in the second year of treatments ($P < 0.05$).

The changes of N that occurred from September 18 to January 20 in different parts of the tree are tabulated in Table 2. Between September and January, there was a net increase of N (5.3–9.1 g) in +N trees, but not in −N trees. The accumulated N in perennial parts of deciduous trees during autumn may come from two different sources: the remobilized N from leaves before abscission (Titus and Kang, 1982; Blasing et al., 1990) and the newly absorbed N from the soil (Taylor and van den Ende, 1969, 1970; Weinbaum et al., 1978; Titus and Kang, 1982; Tagliavini et al., 1999). About 50% of leaf N is remobilized to perennial parts during senescence in apple (Oland, 1963), pear (Sanchez and Righetti, 1990), and peach trees (Niederholzer et al., 2001). The remobilized leaf N constitutes more than 80% of the N accumulated in perennial parts of peach trees (Niederholzer et al., 2001). In our study, however, leaf N changed little in a +N tree during autumn, while N in perennial parts of that tree increased by more than 4.28 g (Table 2). Since our sampling for perennial parts was done 70 days later than the leaves, the N increased in perennial parts could be due to the N absorbed after leaf harvest. However, this possibility was unlikely because little N was absorbed in our trees from January 20 to April 1 (data not shown). N uptake efficiency was less than 3% in dormant prune trees (Weinbaum et al., 1978). Results suggested that accumulated N in perennial parts during autumn was mostly due to the N taken up by the root rather than the N remobilized from the leaves. On the other hand, leaf N in the −N trees decreased during autumn by an average of 0.5 g, 25% of the leaf N on September 18. Higher

Table 1
Nitrogen (N) content during the winter in different parts of persimmon trees fertilized (+N) or not (−N) with nitrogen in the autumn when they were 3 (FY) and 4 (SY) years old

Treatment		Nitrogen content (g/tree)						
Year	N[z]	Leaves[y]	Fruits	Perennial parts				Tree Total
				Shoots	Old woods	Roots	Total	
Expt. I (2002–2004)								
FY	–	1.02	0.63	0.31	0.88	1.72	2.91	4.56
	+	2.04*	1.77*	0.76*	1.88*	4.91**	7.55**	11.36**
SY	–	1.17	0.77	0.36	1.35	1.44	3.15	5.09
	+	3.45***	1.97*	0.99**	4.45*	7.60***	13.03**	18.45**
Expt. II (2003–2005)								
FY	–	2.63	1.37	0.99	1.86	2.74	5.59	9.59
	+	3.20*	2.24*	1.20 NS	2.45*	4.76*	8.41*	13.85**
SY	–	1.21	1.46	0.50	1.60	1.85	3.95	6.62
	+	3.71***	2.78**	1.30***	3.82***	7.35***	12.47***	18.97***

NS: Nonsignificant and *: significant at $P < 0.05$, **: significant at $P < 0.01$, or ***: significant at $P < 0.001$.

[z] Trees were supplied with N in autumn every year of each experiment. A total amount of N applied: (−), 0 g; (+), 22.5 g.

[y] Leaves and fruits were harvested on November 10, and the other plant organs on January 20.